

A SIMPLE MILLIMETER-WAVE BLACKBODY LOAD

Peter H. Siegel

California Institute of Technology Jet Propulsion Laboratory, Pasadena, CA

Robert H. Tuffias

Ultramet, Pacoima, CA

Philippe Goy

AB Millimetre

52 Rue Lhomond, Paris, France

ABSTRACT

A very simple black body calibration target is described for millimeter and submillimeter wavelengths. The target combines random scattering, impedance matching and power absorption to produce a low return loss to incident radiation over a broad range of wavelengths. The design uses a unique light-weight silicon carbide based open cell foam [1] coated with a commercially available ferrite absorbing resin [2] to provide both high thermal conductivity and a high absorption coefficient. The cell size of the foam can be used to tailor the frequency range of operation. Materials other than silicon carbide can be used to form the foam base if different thermal or mechanical properties are desired without greatly affecting the absorption coefficient. This design is an alternative to much more difficult to fabricate periodic scatterers/absorbers [3-7] which perform a similar function.

INTRODUCTION

At millimeter and submillimeter wavelengths high quality absorbing loads are typically fabricated from flat sheet carbon loaded polyurethane foams [8]. These foam absorbers provide low return loss and easy-to-contour surfaces for a wide variety of applications, including room temperature or cooled black body calibration targets, absorbing apertures, anechoic chambers etc. Unfortunately, the base material for these absorbers degrades and crumbles over time periods as short as a few years, the thermal conductivity is only moderate, and for vacuum applications, the material outgasses significantly. Absorbers based on silicone have recently become popular [6,9] but these are unsuitable for vacuum applications due to outgassing and typically are more resonant (frequency dependent) than the open cell foam absorbers. One company [10] produces a polypropylene based carbon loaded absorber which is suited for very high frequencies, but which has so far proven unacceptable for spaceborne applications (again due to outgassing) and for producing black bodies which rely on thermal conductivity to keep the gradient through the material low. Alternative rigid absorbers are available [3,5,11 for example] in an assortment of cast or machined shapes which don't have outgassing, thermal conductivity or lifetime problems. However, these rigid

absorbers, which generally rely on ferrite loading for their absorbing properties, are extremely heavy and, for millimeter or submillimeter wave applications, must be very precisely machined or cast into finely pointed periodic surfaces so as to present the proper dielectric match to the incident RF fields. This usually entails one of two techniques: (1) machining or casting the surface of the material so as to form tapered cones, ridges or pyramids which are sized and spaced on a period akin to a half wavelength or less at the desired frequency of operation or (2) molding or coating the material on a very large aperture structure with a slow geometric taper (slowly tapering cone for example) that allows multiple bounces of the incident RF energy before it can emerge or scatter from the absorbing body.

In this short paper we propose a load composed of a base similar in structure to the polyurethane foam, but with high thermal conductivity, no degradation over time, and no outgassing. The load is made from a sheet of specially prepared silicon carbide open cell foam which is simply dip coated with a layer of commercially available castable ferrite absorber. The coating increases the absorption coefficient of the base material without significantly changing the matching/scattering properties of the open cell foam. The impedance match to the RF field is accomplished through judicious choice of the base material cell size, which can be fabricated with a lattice constant from a few millimeters to less than a tenth of a millimeter and thereby cover a frequency range from below 100 GHz to at least 1 THz and probably higher. The load is extremely easy to fabricate, once the base material and castable resin are in hand, and, although flat sheets are the simplest to implement, more complicated geometries are not excluded.

FABRICATION

The load is based upon the availability of large, fairly thin (0.5-1 inch thick) sheets of the silicon carbide (or similar structured) open cell foam [1] and medium viscosity castable resin absorber [2]. The silicon carbide sheet is placed in a disposable tray or on top of a permanent metal plate (if it is to be used in reflection) and the castable resin absorber is simply poured through the cell structure allowing it to pool at the bottom of the tray. In our samples we used Emerson and Cuming CR117, which has the viscosity of syrup when heated to 150F, and is easily cured in an oven under standard atmospheric pressure. To improve the uniformity of the coating the foam sheet (9x12x0.5 inches thick in this case) was actually soaked in a tray of resin, flipped several times and then transferred to a metal pan where the resin was allowed to drip naturally through the material and pool to a thickness of approximately one-quarter inch at the bottom of the pan. After curing in an oven for one hour at 200C, the load was permanently adhered to the metal pan. In the measurements to follow, two sheets were fabricated and then joined together to form a rather large wedge (Figure 1) providing a large aperture for the incident RF beam and several bounces off the material to mimic the arrangement described in [5]. A cell spacing of 10-15 pores/inch was chosen to optimize the load performance around 200 GHz. The large pore size (near a half wavelength) provides both a randomly rough (on the wavelength scale) surface to enhance non-preferential scattering and a low impedance (average of CR117 and open area) to better match to free space.

RF PERFORMANCE

The RF performance of the new SiC coated load, used both as a wedge and in flat sheet was measured using the arrangement shown in Fig. 2. A special vector network analyzer [12], with a very wide dynamic range at submillimeter wavelengths, was used to measure the return loss off the metal backed load and compare it to a similar load made of rigid absorber (also CR117) cast in a periodic arrangement of 0.15 inch high pyramids (Fig. 3) and flat sheet foam absorber (Eccosorb AN74). Photographs showing the surfaces of each measured load and their performance over frequency are displayed in Figs. 4 and 5. As is apparent from Fig. 5, the silicon carbide load worked as well or better than the much more difficult and expensive to fabricate pyramidal absorber in flat sheet form and almost as well in the wedge arrangement. In addition, the silicon carbide absorber had little (if any) polarization dependence whereas any periodic absorber must be designed so as to eliminate large reflections at specific angles due to diffraction lobes. The foam absorber was superior to both rigid absorbers at the higher frequencies but comparable or poorer performing below 200 GHz, as might be expected from the smaller cell size compared to a wavelength at these frequencies. Flat sheet CR117 (with no surface roughness machined in) performs very poorly with less than 10dB return loss at most frequencies. The measurements also indicate the performance enhancement that occurs with frequency when the cell size (or periodicity in the case of the pyramids) is appropriately chosen. This feature was chosen to be best suited to a measurement frequency near 200 GHz for both of these loads. Additional frequency tailoring can be accomplished by altering the surface contour of the silicon carbide foam on a scale large compared to the cell size, like the arrangement often used at lower frequencies with the polyurethane and silicone based absorbers found in anechoic chambers. Finally, although thermal conductivity measurements on the load were not made, the inherent thermal conductivity of the silicon carbide base material is very high compared to polypropylene, silicone or even the castable absorbing resin, so it is expected that this load will perform at least as well as the rigid pyramidal type absorber and better than absorbers based on other materials.

OTHER APPLICATIONS

Uses for the proposed black body absorber are not limited to millimeter and submillimeter wavelengths. The principle of operation, i.e. scattering and impedance matching at the surface of the material, apply to any frequency and the foam base can be cast in any geometric arrangement desired. This means much lower frequency operation is possible and less costly base materials might be employed for large coverage areas. Obvious benefits of the silicon carbide base material are imperviousness to high temperatures, resistance to physical loading and high thermal conductivity. Pure carbon foam has also been coated successfully, but does not have the resistance to breakage and flaking inherent with the silicon carbide. Non absorber related applications for the material may exist but are not a concern here.

SUMMARY

A simple absorbing black body load can be formed by combining an open cell silicon carbide based foam and a castable ferrite absorbing resin. The resulting structure is easy to fabricate and performs as well as much more expensive and difficult to build periodic absorbing surfaces. Applications are not confined to high frequencies if the base material is formed into geometric shapes compatible with the frequency of application. The cell size of the base material can be adjusted to peak the absorption at a particular wavelength if desired.

ACKNOWLEDGEMENT

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REFERENCES

- [1]. The silicon carbide foam is available in sheet or custom shaped form from Ultramet, Pacoima, California, 91331, 818-899-0236. It is produced using a proprietary process employing CVD deposition and can be produced with base materials other than silicon carbide.
- [2]. A variety of microwave absorbing resins are available from Emerson and Cuming Microwave Products, 28 York Avenue, Randolph, Massachusetts 02368 781-961-9600. The resin used to make the loads described in this report is Eccosorb CR117, which has one of the highest absorption coefficients, but any of the CR series resins could be used depending on the application.
- [3]. J.M. Stacey, "Microwave Blackbodies for Spaceborne Receivers," JPL report 85-10, March 1, 1985, 40 pages.
- [4]. P. Goldsmith, R. A. Kot and R.S. Iwasaki, "Microwave radiometer black body calibration standard for use at millimeter wavelengths," Review of Scientific Instruments, vol. 50, no. 9, pp 1120-1122, Sept. 1979.
- [5]. D.A. Hills, "Reflection response of the MLS Radiometer Calibration Load," IOM DLH-8606-02, June 6, 1986.
- [6]. R.H. Giles and T.M. Hogan, "Silicone-Based Wedged-Surface Radiation Absorbing Material," US Patent No. 5,260,513, Nov. 1993.
- [7]. S.Janz, D.A. Boyd and R.F. Ellis, "Reflectance Characteristics in the Submillimeter and Millimeter Wavelength Region of a Vacuum Compatible Absorber," Int. Journal of Infrared and Millimeter Waves, vol. 8, no. 6, pp. 627-635., 1987.

[8]. Emerson and Cuming, as well as other companies, produce a variety of polyurethane foam based broadband carbon loaded absorbers. The most common example of which is the Eccosorb AN series.

[9] Silicone based absorbers loaded with absorbing ferrite generally come in flat sheets (Eccosorb FDS or GDS) or can be molded into wedges like the material referred to in [6].

[10]. A polypropylene based molded pyramidal absorber for millimeter and submillimeter wavelength operation "Tessalating Terahertz RAM" is available from Thomas Keating Ltd., Station Mills, Billingham, West Sussex, RH14 9SH, England. This material has so far proven to be unsuitable for space application due to outgassing (probably fixable) and has a low thermal conductivity (not fixable), making it less desirable for high quality black body calibration loads which must have front-to-back surface thermal gradients which are extremely small.

[11]. Emerson and Cuming MF series for example.

[12]. AB Millimeter MVNA with ESA1 and ESA2 extensions.

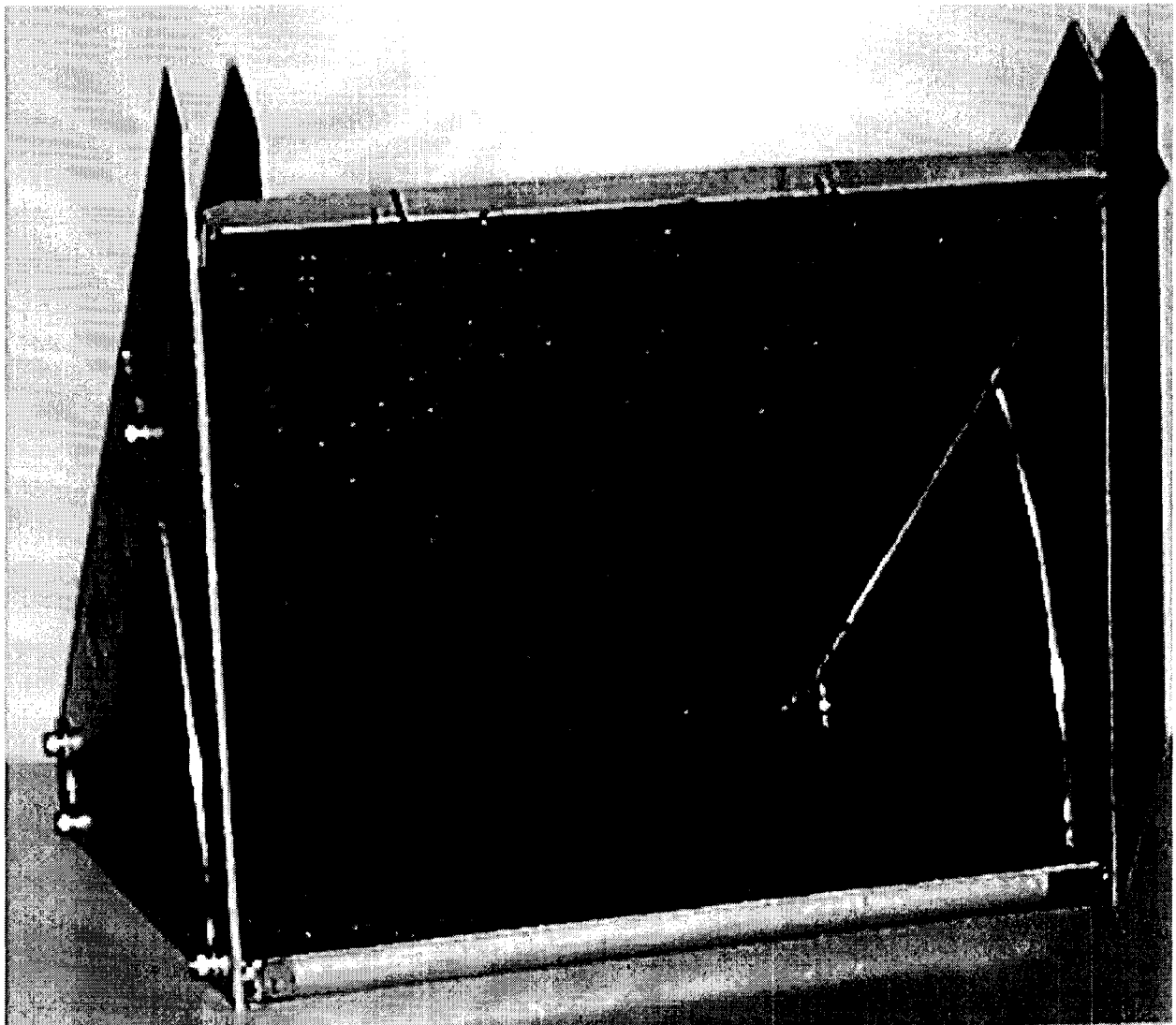


Figure 1. CR117 coated Silicon Carbide load formed from two sheets of material (9x12 and 9x9 inches by 0.5 inches thick) joined together to form a wedge. The wedge allows multiple bounces of the incident RF energy, enhancing absorption. No material is present on the sides of the wedge. Incident RF energy is contained within a beam which fits within the projected aperture of the angled absorbing sheet. The wedge can handle a large beamwidth but the absorber thickness (0.5 inches) limits the lower frequency of operation to about 100 GHz. Slots on the sides allow the wedge angle to be altered between about 20 and 45 degrees to achieve the best performance for a given beam diameter.

Measurement Set-Up

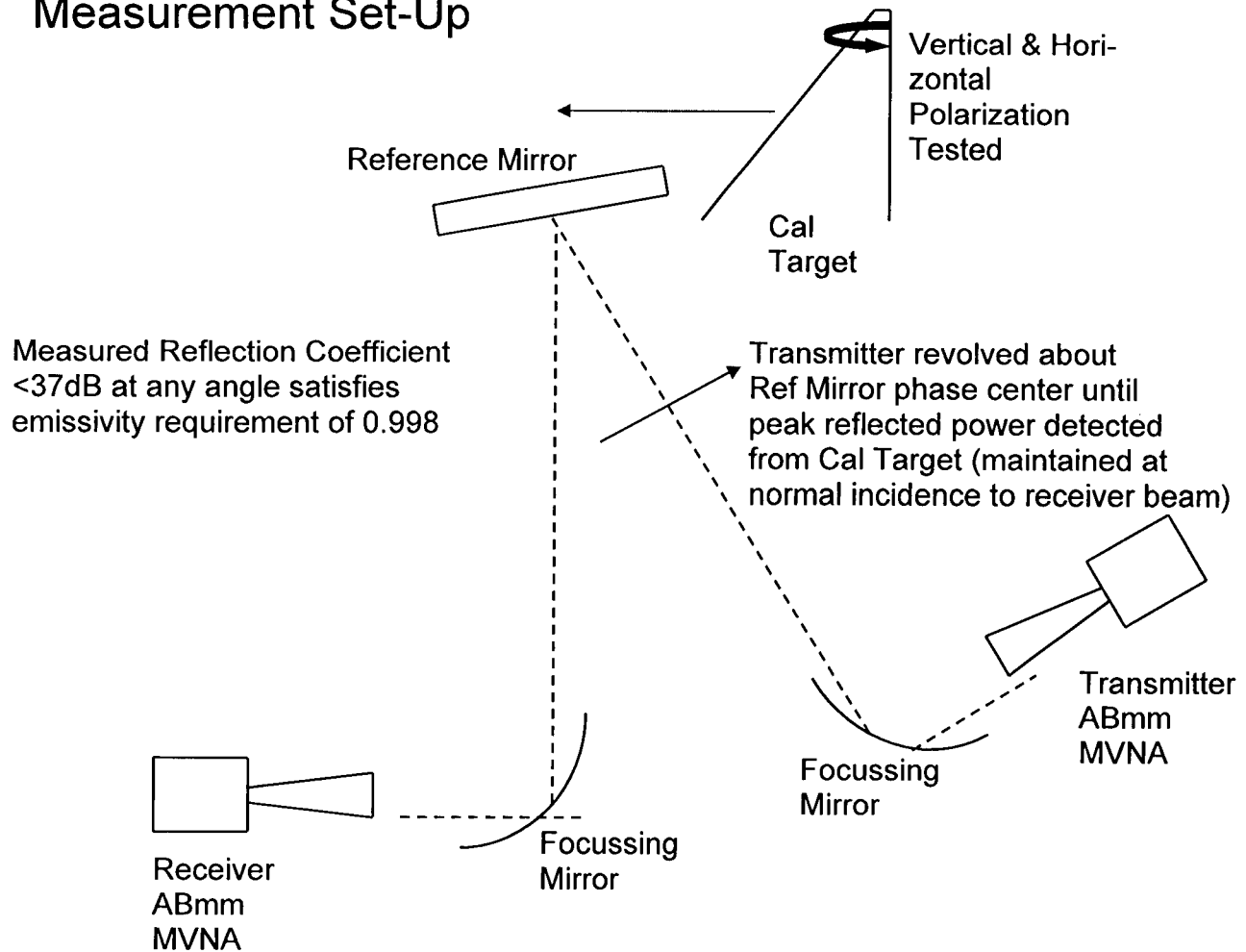


Figure 2. Measurement set up used to determine the reflection coefficient (and derived emissivity) of the load material at any incident angle. During measurements the wedge and flat sheet absorbers were fixed while the transmitter was rotated through angles from 20 to 60 degrees. The maximum received power was recorded with reference to a reflecting mirror. The absorber based on a periodic grid of small pointed pyramids showed specific angles with peak power reflection (due to grating lobes) whereas the foam absorbers showed sinusoidally varying power versus angle related to the standing wave structure set up by the varying penetration depth of the RF energy into the load.

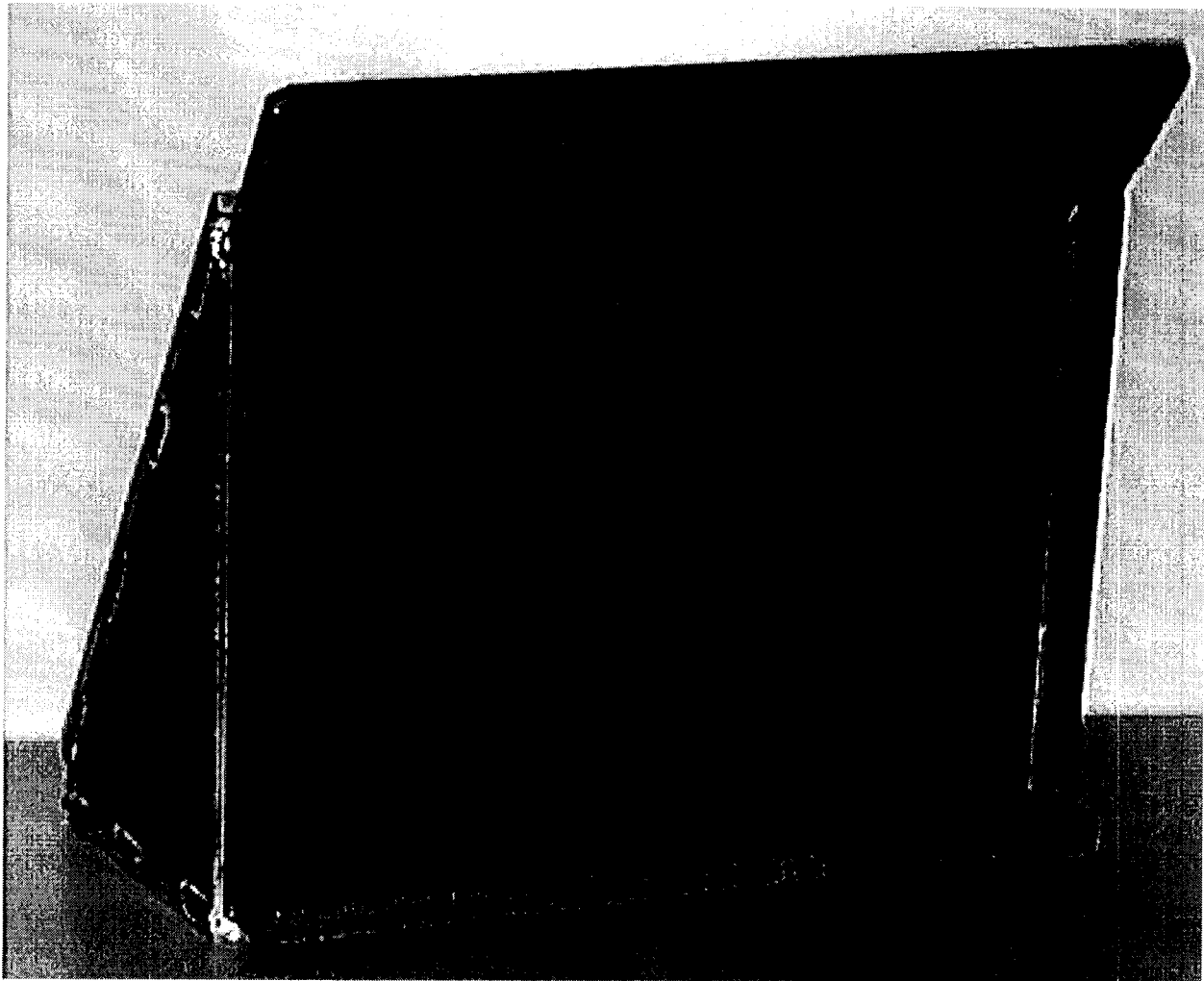


Figure 3. CR117 cast periodic pyramidal absorber formed in the same wedge geometry as the silicon carbide foam load. The pyramids are barely visible, but are roughly .15 inches high and .1 inch apart with a 25 degree taper angle. The wedge angle is approximately 42 degrees. The incident beam is parallel to the table and hits the angled plate of the wedge near the center before bouncing off the lower plate and into the apex of the wedge. Both the wedge and single flat sheet were measured. The material at the base of the pyramids (which give the load considerable weight, but bind the cones together and is equivalent to the pooled CR117 at the bottom of the silicon carbide foam load) is about .2 inches thick.

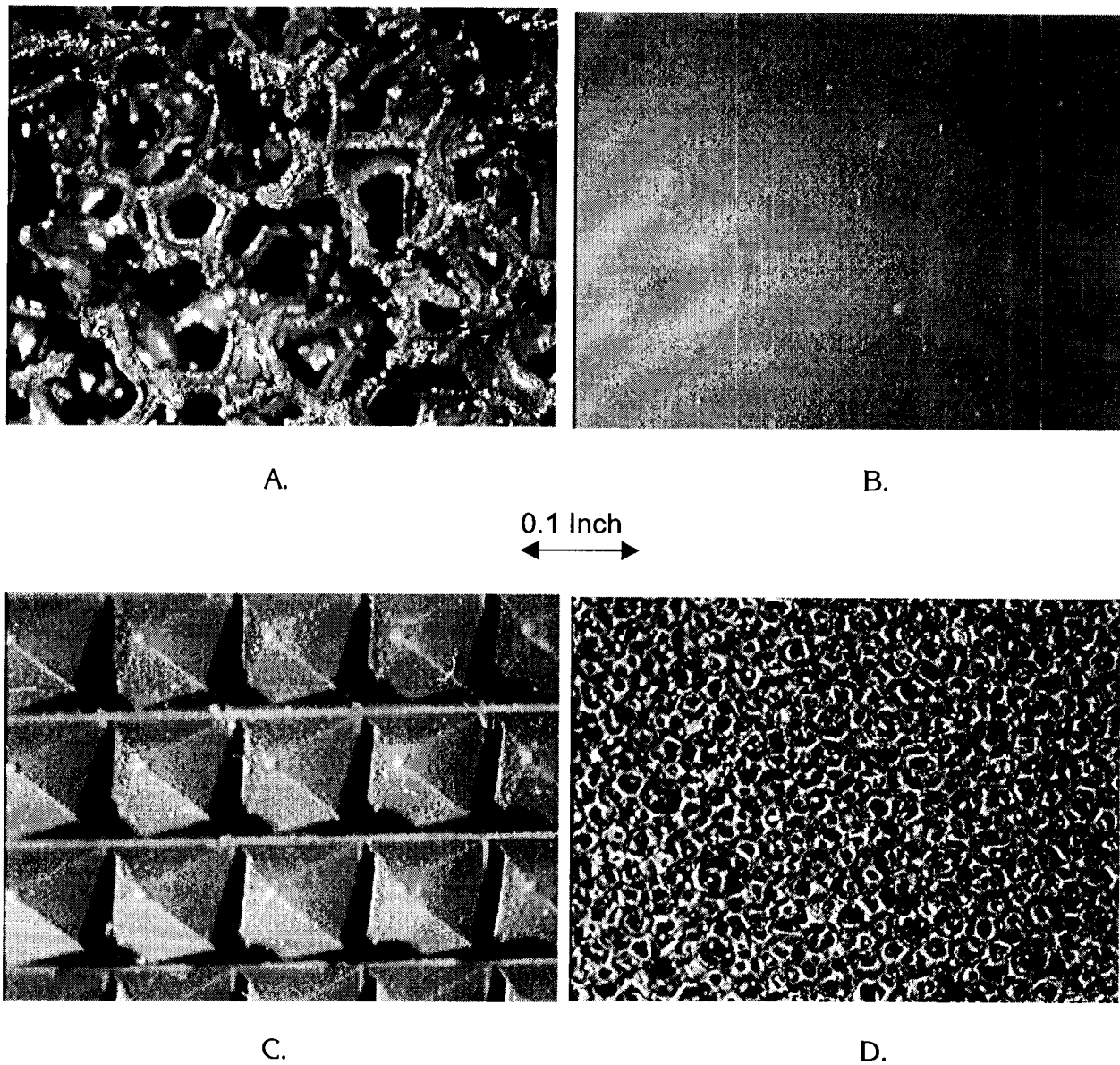


Figure 4. Photographs showing each of the loads tested, at the same scale.
(A). New CR117 coated Silicon Carbide foam.
(B). CR117 cast in a flat sheet.
(C). CR117 cast into pyramids and arranged in a periodic pattern suitable for 200 GHz. (D). Typical carbon loaded polyurethane foam absorbing sheet – AN74.

Load Measurements: Worst Case Return Loss

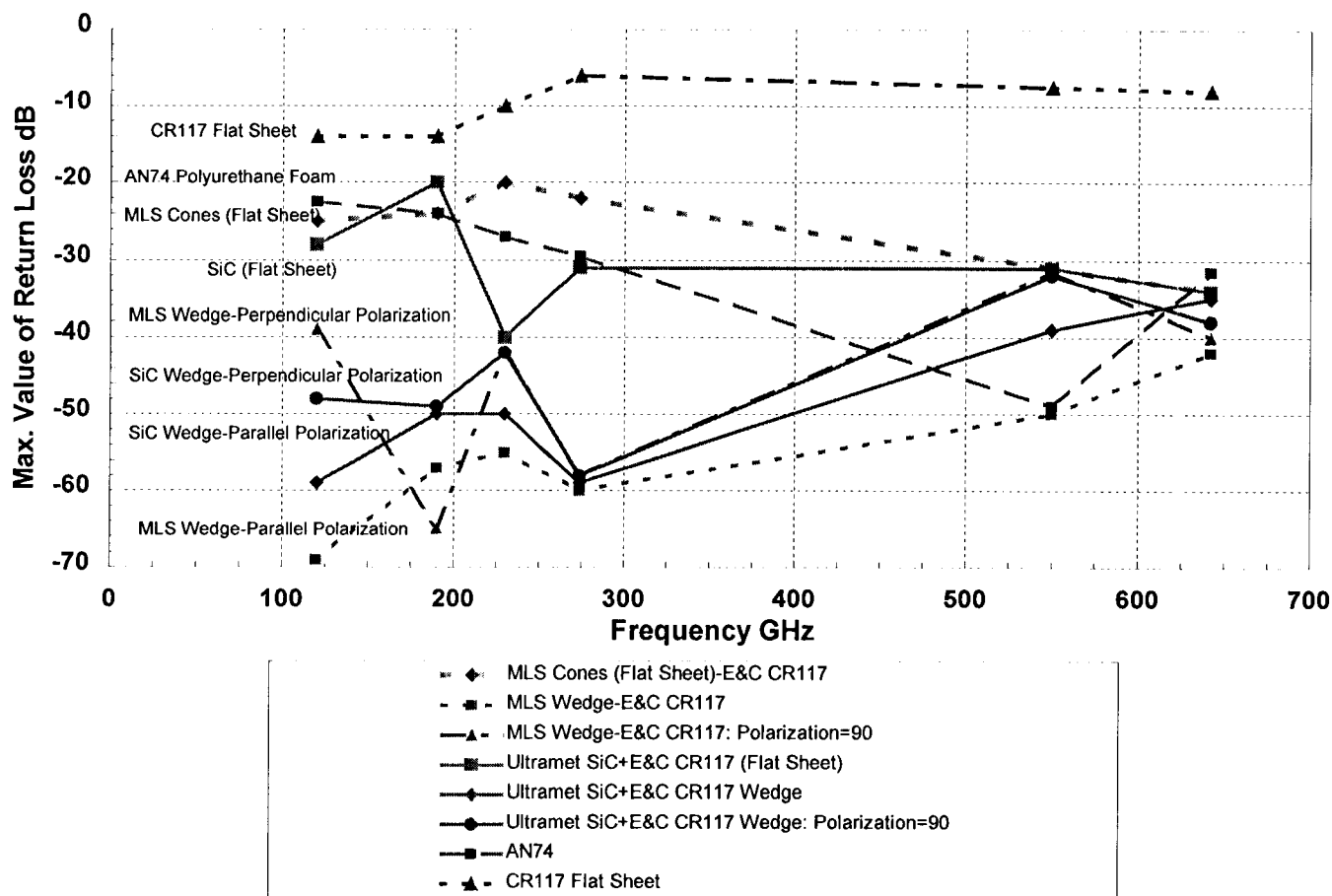


Figure 5. RF measurements showing the peak reflected power as a function of transmitter angle off the wedge and flat sheet absorbers at different RF frequencies and two polarizations (E field vertical and horizontal). Note that the AN74 performs better than either the pyramidal cones or SiC flat sheet load at higher frequencies but similarly near the resonant wavelength of 200 GHz. Flat sheet CR117 is very poor by comparison. The dynamic range of the test set limits the load performance at 600 GHz.